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Abstract

This paper analyzes the sources of the slowdown in productivity growth in the US and other major OECD nations. It presents a medium term structural macroeconomic model for interpreting the interdependence between inflation, total capital formation (human, physical, and knowledge capital), and the basic sources of labor productivity growth.

The major sources of the slowdown based primarily on a production function estimated for 15 nations are found to be the underutilization (labor hoarding) and reduced physical capital investment due to restrictive monetary policies that followed the 1973 and 1979 energy and other supply price shocks. Oversize and overactive government and increased environmental regulation are rejected as sources after investigation. But the loss of the advantages of backwardness (i.e. follower countries, most notably Japan, have had an advantage in not having to develop the basic technology), and the Baily effect (i.e. obsolescence due to energy shocks) are the third and fourth significant factors.

Human capital formation, measured as increased educational attainment, is found to be significant to productivity growth, but the per student cuts in real terms have come later than the onset of the slowdown. Lower nondefense R&D effort in the US and UK relative to that in Germany and Japan is found to be a less significant factor, although it may operate with a longer lag.

Sources of the Slowdown in Productivity Growth: A Structural Interpretation

Walter W. McMahon

This paper presents an analysis of the sources of the productivity slowdown in the U.S. with comparisons to other nations. It presents a structural interpretation of recent work by Maddison on the "Dynamics of Productivity Growth" (1979) and Phases of Capitalist Development (1982), as well as of the results of Denison's (1979, 1982) and Kendrick's (1980) analyses, that encompasses Maddison's useful grouping of "conjunctural" and "non-conjunctural" sources of the slowdown in productivity growth. That is, a more explicit simultaneous equation model is presented here that incorporates those sources related to slack demand and low investment following the 1973 and 1979 energy price shocks and of non-conjunctural sources related to the "loss of the advantages of backwardness."

Both of these are important sources of the slowdown, in my opinion, and consistent with some independent evidence which I will present. But there are additional sources of productivity growth appearing in the work by Denison (1983), Schultz (1983), and Kendrick (1980) that are consistent with a broader concept of total capital. These include investment in human capital, primarily via formal education and on-the-job training, as well as investment in new knowledge-capital primarily through investment in those types of R&D most directly related to technical change and improvements in efficiency. Some empirical evidence consistent with these points will also be presented.

It is my hope that a structural interpretation of Maddison's two key sorces augmented with this concept of total capital, will help to provide an increasingly adequate explanation of the sources of the slowdown as well as of some of the possibilities for resumed labor productivity growth in the late 1980's and in the 1990's.

Sources of the Slowdown--A Structural Interpretation

Maddison's two key sources, as well as the sources developed by Denison (1979, 1983), to whose work we owe much of what is known about this subject, are reflected primarily through a production function. Some such production function is the common structural frame of reference and must be the centerpiece of any structural model dealing with productivity growth.

The production function presented below as well as the rest of the model to be presented later refers to the medium term, which allows capital deepening to occur, and its rate to have some effect on productivity growth. The medium term however also allows there to be adverse effects on productivity growth from underutilization of human capital (Maddison's "labor hoarding") as well as of physical capital (excess capacity) due to slack demand. This specifies a disequilibrium model in the sense that cautious demand management policies give rise to stock disequilibrium (e.g., excess capacity of human and physical capital) as well as to reduced capital deepening, all the while with flow equilibrium in the products and money markets, in contrast to a focus on long run steady state growth solutions.

Starting with a Cobb-Douglas production function that includes human capital and also (disembodied) stocks of knowledge-capital consistent with work by Denison (1983), Schultz (1983) and Kendrick (1976), taking the natural logs, and differentiating with respect to time gives the growth rate of real Gross Domestic Product (y) as a function of the rate of growth of the various inputs. The rate of growth of the number of persons employed (n) may then be subtracted from both sides under the simplifying assumption implicit in Maddison's paper of constant returns to scale to determine the rate of growth of output per worker. The result is the determinants of labor productivity growth as shown below in Equation (1). (The production function from which it can be derived is shown in the Appendix.)

$$(1) \qquad (y-n) = \gamma_1 U_{H,K} + \gamma_2 (Y/N)_{-1} + \gamma_3 (k-n) + \gamma_4 (h-n) + \gamma_5 a + \gamma_6 (e-n)$$

In the empirical estimates below, each variable is measured as the average for five year periods (the medium term) between 1955 and 1980, where:

$(y-n)$ = <u>labor productivity growth</u>, measured for Table 1 below as the percent rate of growth in real GDP per person employed for the OECD nations,

$U_{H,K}$ = <u>percent underutilization of human and physical capital</u>, measured below by assuming that slack demand and hence underutilization of both is measured by the percent unemployed, for which data exists,

$(Y/N)_{-1}$ = <u>the initial level of output per worker</u> at the beginning of each new five year period--Maddison's "advantages of backwardness,"

$(k-n)$ = <u>the rate of physical capital formation (k) per worker (n)</u>. It is measured in Table 1 as Gross Private Domestic Investment as a percent of base year GDP, per person employed. Gross Investment allows for the embodiment of new technology through replacement investment, and is consistent with the use of GDP rather than NIPPE for y. Base year GDP in the denominator substitutes for capital stock data (which does not exist for many countries other than the U.S.).

(k-n) = the rate of human capital formation per worker, measured for Table 1 as the increase in the average educational attainment of the working age population,

a = the rate of increase in disembodied technical knowledge, measured for Table 1 as non-defense public and private R&D investment at the beginning of each new five year period as a percent of GDP in that year, and

(e-n) = the rate of change in petroleum-energy use per worker, measured in Table 1 as the percent change in net oil imports plus domestically produced and consumed oil per person employed.

This offers a framework for considering and independently evaluating the relative importance of the conjunctural and non-conjunctural forces, the latter including human capital formation and R&D. I will discuss the results of the various estimates of equation 1 below, starting with the conjunctural forces which are associated with the effects of underutilization.

The Effects on Productivity Growth of Underutilization

But first, the fact that the slowdown in growth (and hence also in productivity growth) has been experienced in all of the major OECD countries since 1973 as may be seen in the top of Table 2 below is significant because it forces attention to factors that are not unique to the United States. The restrictive demand management policies used in all of these nations following the 1973 and 1979 oil price shocks with their adverse effects on capital formation per worker, (k-n) in Eq. (1) above, and on underutilization of human and physical capital, $U_{H,K}$, (which includes Maddison's "labor hoarding") fill this bill, whereas suddenly changing patterns of union strength, management efficiency, or government size do not.

To attempt to appraise these two conjunctural forces, consider the regressions shown in Table 1 using equation (1). They seek to explain productivity growth since 1955 in 15 OECD nations including the U.S. in 5 year periods, which yields 75 observations. Notice that the effect of slack demand as measured either by the percent of unemployment (U) or by changes in unemployment, both of which are adjusted for differences in measurement among countries, is always a significant factor and (except in an insignificant instance) always has the expected sign. This is consistent with the proposition that low utilitization rates are an important source of slow productivity growth. The rate of physical capital formation per worker, (k-n), also has the expected effect on productivity growth. Its significance is consistent with the proposition that higher capital formation raised productivity prior to 1973 and lower capital formation since that time slowed it. This result is also consistent with a stress on the conjunctural forces related to cautious demand management policies, particularly monetary policy, following the two energy price shocks.

I must add, however, an important refinement. The lower rates of physical capital formation per worker, and it is capital formation _per worker_ that is relevant to productivity growth, were also the result in the U.S. of a large wave of new workers entering the labor force in the 1970's picked up by (k-n) in the regressions. This can be seen in the data on employment in these nations. The big wave of postwar births entering the labor force in the U.S. was not matched by comparable

Table 1

Growth in Labor Productivity

Dependent Variable: Productivity Change Over 5 Year Period (y-n) for Each Country

FIFTEEN OECD NATIONS:

Independent Variables:	1955-1970 Coef.	1955-1970 t-statistic	1955-1980 Coef.	1955-1980 t-statistic
Underutilization (Av. U)	-1.23	-1.52	-1.50	-2.60
Initial Productivity $(Y/N)_{-1}$	-11.23	-2.62	-10.70	-3.10
Physical Capital Deepening (Av. I/Y_{-1}-n)	.81	3.38	.67	3.63
Human Capital Deepening (h-n)	.05	2.02	.02	1.22
Energy Charge per Worker (e-n)	.00	.38	.01	1.17
Constant (eg., Stocks of Knowledge)	.14	1.70	.16	2.32
Number of Observations =	45		75	
R^2 =	.57		.54	

FIVE LARGEST OECD NATIONS:

Independent Variables:	1955-1970 Coef.	1955-1970 t-statistic	1955-1980 Coef.	1955-1980 t-statistic
Underutilization (Av. U)	-3.21	-1.70	1.37	.37
Change in Utilization (μ)	-3.67	-3.68	-3.67	-2.18
Initial Productivity $(Y/N)_{-1}$	-6.76	-1.35	-5.01	-.49
Physical Capital Deepening (k-n) = (Av. I/Y_{-1} -n)	1.01	3.45	1.67	2.29
Human Capital Deepening (h-n)	.32	6.41	.04	.50
R&D Knowledge Formation a = $(R\&D)_{-1}/Y_{-1}$	-.05	-1.23	-.10	-1.09
Energy Charge per Worker (e-n)	.002	.46	.002	.25
Number of Observations =	15		25	
R^2 =	.97		.68	
Simple Correlation, (y-n) with $(R\&D)_{-1}/Y_{-1}$	.16		-.12	

increases in France, Germany, Japan, or the U.K., where total employment remained stable in this period, with the result that the dilution of the amount of capital per worker would operate to contribute to relatively slower productivity growth in the U.S.

Loss of the "Advantages of Backwardness"

The second major source of the slowdown is the longer run loss of "technological backwardness" as Europe and Japan catch up to the U.S. It is reflected in the initial productivity level term in Equation (1) and Table 1, which will also reflect the Rosenberg (1976) effect. Rosenberg's basic idea is a reasonable one, that the process of research, and of trial and error in innovation, impose constraints on the pace of development of knowledge in the lead country. This is a burden borne by the United States that is now shifting in some product lines to Germany and Japan.

The "advantages of technological backwardness" helps to explain a somewhat faster growth outside the U.S., such as in Japan, where the level of productivity was far behind that in the U.S. in 1960, as well as somewhat slower growth in the U.S. where many of the costs of technological leadership and innovation are borne. In Table 1 the initial productivity level representing this effect does have the expected negative sign, and higher initial levels are significantly associated with relatively slower productivity growth in all regressions. This result is consistent with the conclusion that the advantages of backwardness are an important factor, and that their loss can slow a nation's labor productivity growth rate.

Human Capital Formation

A major factor that I would like to discuss next is the signficance of human capital formation to the productivity growth process. This factor also appears in the work by Denison (1983), Schultz (1983), and Kendrick (1980).

When human capital formation per worker as measured by increased average educational attainment of the working age population is introduced as shown in Equation (1), it always turns out to have the expected positive sign. It is a significant factor explaining productivity growth in the relatively stable period from 1955 to 1970. It continues to have a positive relation to productivity growth in the unstable period from 1970 to 1980. Of course there is some two way joint dependence between human capital formation and per capita income growth. But if on further investigation the simultaneous bias should turn out to be small, this tentative estimate suggests that even this limited measure of human capital formation accounts for a significant fraction of the productivity growth in the postwar period in the developed nations.

When this measure of basic literacy in mathematics and language is augmented with a measure of the number of trained scientists and engineers as a percent of the labor force in each industry, it explains how it is possible for the follower-county to adapt and use effectively the new technologies. This step is essential to be able to capitalize on the "advantages of backwardness." There are many LDC's that have not equaled the growth record of Japan and Israel, for example where large initial stocks of human capital and higher rates of growth in education and health levels in both countries have undoubtedly made it easier for them to use western technology. The level of educational attainment in Japan was not only high initially, but the rate of increase has been considerably higher than that in the U.S. or the UK since 1950! This seems to me to be an essential supplement to Maddison's (1979) mention of trade as the main transmission mechanism. Although importing high technology capital goods undoubtedly transmits some kinds of new technology, there are still significant steps before these items, and perhaps even more important the more intangible kinds of scientific findings (e.g., uses of hybrids in agriculture) can be made effective in production.

This is consistent with what is being found in an increasing number of studies of productivity growth in the less developed countries. To cite only one example, there is an interesting recent study by Yamada and Ruttan (1980, p. 559) of the sources of productivity growth in agriculture in 41 developed and developing countries. They find that the number of graduates of agricultural colleges per person employed in agriculture (which helps to facilitate the dissemination of technology as well as mobility out of lower productivity agriculture into agribusiness), supplemented by the average educational attainment of persons in agriculture, accounts for 30-32 percent of the productivity differences in agriculture among developed as well as among less developed countries.

This is not to suggest that reduced human capital formation has as yet been more than a minor source of the slowdown in productivity growth. This is largely because investment in education is not as sensitive to restrictive monetary policies as is physical capital investment, mostly because relatively less human capital is financed with credit or sensitive to changes in credit terms. Nevertheless, there is some evidence that there may be a greater reduction in the rate of effective human capital formation than is revealed by the figures. For example, the quality of education has fallen in the U.S. in some respects since the late 1960's as evidenced by the reduced requirements in high schools for courses in math and science, and the falling math and science scores on college admission and graduate record examinations. A weakening in college curricular requirements occurred in the U.S. as well as in Japan and elsewhere at the time of the campus unrest of the late 1960's. Furthermore, human capital formation in the form of on-the-job training, has been sharply reduced for those unemployed during the 1975 and 1982 recessions. Public support for education now is being cut severely by Federal and state government budget cuts in the U.S. All of this is likely to reduce the rate of embodiment of new technology in the new human capital as it is formed, with effects that although they may have been modest since the late 1960's are likely to be more important as growth rates are computed that link 1970 to productivity levels in 1985 and beyond.

The further significance of this is that some of the key sources of the slowdown, such as the sharp reductions in energy-intensive investment associated with the Baily effect, are not strictly reversable. The same kinds of energy-intensive investment cannot merely be resumed. This suggests that perhaps somewhat more attention needs to be paid to less energy-intensive sources of productivity growth such as human capital formation. It can be interpreted to include improvements in the quality of management as well as the embodiment of the new technology.

Advances in Knowledge Through R&D

There are now new data on the composition of public and private investment in R&D, some of which is summarized in Table 2. Some types of this R&D may reasonably be viewed as more relevant to productivity growth than other types. For example, Japan's much larger investment as a percent of its GDP for support of adaptation of western technology relevant to agricultural productivity, industrial productivity, and energy shown in Table 2, as well as its much smaller total public defense R&D effort relative to that in the U.S. and U.K. could help to partially explain slower growth in the U.S. and U.K. as well as the shift of technological leadership to Japan in an increasing number of product lines. The Rosenberg (1976) effect and diminishing returns to R&D have the potential of helping to explain the slower growth in the U.S., but not the assumption of new leadership by Japan. The explanation therefore needs to be augmented, in my opinion, with the effects of investment in some types of advances in knowledge, a second aspect of total investment and capital. Germany's non-defense R&D effort has even more dramatically exceeded that in the U.S. and the U.K. since 1965 (see Table 2).

Some will argue that new weapons systems and space exploration have spillover effects on productivity growth--perhaps this is Maddison's implicit assumption in looking at total R&D where the U.S.

Table 2

Growth Rates and Composition of R&D Expenditure
Countries Ranked from Fastest (left) to Slowest (right)
Pre-Energy-Shock Growth

	JAPAN	GERMANY	FRANCE	SWEDEN	U.S.	U.K.
Growth Rate Per Capita:						
1966-1973	9.5%	3.9%	4.9%	3.2%	2.9%	2.5%
1974-1980	1.9	2.1	2.3	.9	1.3	.7
Non-Defense Govt. R&D Plus Pvt. R&D As a Percent of GDP:						
1965	1.53%	1.53%	2.01%	n.a.	1.33%	1.49%
1975	1.89	2.19	1.80	n.a.	1.50	1.39
Government R&D by Major Objective:						
Defense	5%	19%	36%	33%	49%	61%
Industrial Productivity	13	15	14	3	.4	10
Agricultural Productivity	30	3	4	3	2	5
Energy	19	21	9	12	10	8
Health	7	6	5	11	12	3
Advancement of Knowledge	0	9	15	5	4	4
Other (e.g., Space, Telecommunication, Environment)	25	27	17	26	23	9.2

Sources: Non-Defense R&D from Science Indication, N.S.F., p. 212
Government R&D by Objective is net of general university funding from Piekarz et al. (1983, Table 10).

clearly leads. But surely those components of R&D directly oriented to improving economic efficiency and productivity or to expanding basic knowledge are likely to have a larger impact on productivity growth than those that are not--see Gilpin (1975) and NSF (1981, p. 9). Defense research also computes for scarce scientific research personnel. Beyond this, the United States devotes a larger fraction of its non-defense research dollars to health R&D than elsewhere. There are many non-monetary returns to health research in the form of a longer and better quality of life for which no imputations are made in the measures of GNP used in calculating productivity growth.

With respect to empirical evidence, total public and private non-defense R&D--the only measure available for the 1960-1980 period, and then only for the five largest OECD countries--has exceeded that in the U.S. in both Germany and Japan since 1968, as can be seen in Table 1. When it is introduced into the regression as shown at the bottom of Table 1, its coefficient somewhat surprisingly is negative, but it is not significant at the .05 level. The simple correlation is positive up until 1970 however as shown in the bottom line of Table 1, after which the more dramatic slowdown that occurred in the high-growth countries (see the top of Table 2) is negatively correlated with their higher R&D efforts. This all suggests that it is likely that there are longer lags involved than those introduced into this particular regression, and that better controls are needed for the effects of underutilization. It also is likely to be fruitful to extend Piekarz' data to measure those types of R&D expected to be more relevant to productivity growth over the entire 1955-1980 period so they could be used in the regressions.

There is some empirical evidence of shifts in technological leadership away from the U.S. The increasing number of U.S. patents secured by foreign inventors, for example, and the decline since about 1967 in the number of patents secured by American inventors (NSF, 1981, p. 110), may also be related to the smaller nondefense R&D effort in the U.S. This smaller effort has been due largely to the decline in Federal support for non-defense R&D, since R&D by industry has continued to grow slowly in real terms, in spite of the lower profits during the 1975 and 1982 recessions (NSF, 1981, p. 75).

Needed Imputations for Environmental Improvements

Turning to Maddison's and Denison's point that increased governmental regulation related to better air, water, and industrial health causes some of the slowdown in productivity growth, I would like to suggest that this is largely because the National Income Accounts fail to make imputations for the returns to better health, for example, as the result of improved air and water quality (via EPA regulations) and improved health and safety in the mines and other industries (via OHSA regulations). Surely these add to utility and satisfaction as do many other final consumer services. We count the costs of cleaning up the environment that are added within firms by the regulations, but then treat it as an intermediate good and fail to count the final product. If the product price is increased as the result of these added costs, it adds to the inflation rate, but, (except for some consumer product safety gadgets), not to the quantity of final output that is measured. Of course one must agree with Maddison, and with Denison, that measured productivity thereby is lower. It is virtually true by definition.

When I attempted some imputations for the improvement to the environment and health brought about by these regulations, based simply on factor cost, plus imputations for the services of housewives that include the dramatic improvement in their education that, as George Psacharopoulis points out, contributes among other things to better health in the family, I found no decline in growth of measured plus imputed GNP per person employed in the period from 1965 to 1973 (see McMahon, 1981, p. 9). Making imputations for the imputed rental value of household capital, as well as the services of housewives, Kendrick (1979, p. 357) found much the same pattern of increasing imputed values from 1966 to 1973. Eisner's (1982) analysis of capital formation by government comes to much the same conclusion--that is, imputed rental values for government-created capital to be added to GNP that grow after 1966.

It is extremely desirable to increase the cost effectiveness of these regulations. But since most of us have by now had experiences such as breathing cleaner air, swimming in cleaner lakes, and observing strip miners replacing the top soil, perhaps it is now time to leave the burden of the proof that these regulations are <u>totally cost-ineffective</u> to those who use data where they have made no imputations for health or environment improvements, thereby valuing them at zero.

But even including some imputations for much of this imperfectly measured final product, there is still a sharp slowdown in productivity growth beginning not in 1966 but in 1973.

<u>Oversized and Overactive Government</u>

When one investigates the hypothesis that an oversized and overactive government is impeding productivity growth and significantly responsible for the slowdown, one finds that total taxes as a percent of GNP are larger in France, Austria, Greece, Belgium, and especially in Germany, than they are in the United States, and that all of these countries have grown faster than the United States, both postwar and from 1973 to 1980. Among OECD countries where the government sector is smaller, only one, Japan, has grown faster, and several, such as Spain, Australia, and Portugal are growing more slowly. I therefore must agree with Angus Maddison (1983); there is no apparent relationship between government size and economic growth or labor productivity.

Enough has been said above, however, to suggest that the <u>structure</u> of government expenditure and taxes can have a significant impact. Some government expenditure is really investment, such as the investment in non-defense research and development, and investment in physical and human capital--areas where significant cuts can have an adverse effect on the technological leadership of the nation and on productivity growth in the longer run. Conversely, some types of government expenditure support only consumption, such as the operation of large unfunded retirement systems or ADC-type welfare systems, which probably operate in the other direction to reduce personal savings rates, physical capital formation, human capital formation, and measured growth.

A More Explicit Model Needed

The needed next step is the construction of a more explicit and more comprehensive model that captures these major effects developed above as well as by Maddison (1983), Denison (1983), Schultz (1983), and Kendrick (1980). The productivity-growth function (derived from the production function) in Eq. (1) above needs to be augmented with a more complete specification of the demand-side, since the simultaneity implicit in the effects of cautious demand management policies is also implicit in most discussions of productivity growth. But except for a few purely theoretical long-term growth models, it is seldom taken explicitly into account.

Such a model is presented in Table 3. Its theme is that slower productivity growth and energy price shocks adversely affect the inflation rate, that the rate of inflation is a significant influence leading to tighter macroeconomic policies (particularly monetary policy), and that these in turn restrict investment demand, capital formation, and the level of utilization of human and physical capital, all of which retard productivity growth.

Most discussions of this subject are in terms of rates of change. So in Table 3 I attempt to set out a consistent structural model in rate of change terms. After the productivity growth equation (1) which was discussed above, the inflation rate is determined through a relatively standard Phillips-type reduced form price equation that is shifted adversely by the slowdown in productivity growth. Eq. (3) determines the rate of growth of the money supply through a reaction function within which this inflation rate appears. Together with the rate of growth in the demand for money in Eq. (4), the slowed growth of the money supply has the net effect of tightening credit terms, r, which in turn restrict gross investment in physical capital stocks in Eq. (6). This in turn slows the rate of growth of aggregate demand

Table 3

A Structural Interpretation of Medium-Term Productivity Growth and of Sources of the Slowdown

Summary of the Model, Incorporating Maddison's Sources and Total Capital

Productivity Growth:

(1) $(y_s - n) = \gamma_1 U + \gamma_2 (Y/N)_{-1} + \gamma_3(k-n) + \gamma_4(h-n) + \gamma_5 a + \gamma_6(e-n),$

$\gamma_1 < 0, \gamma_2 < 0$

Inflation Rate:

(2) $p = \beta_1 U + \beta_2 (y-n) + \beta_3 \pi + \beta_4 p_e,$ $\beta_1 < 0, \beta_2 < 0$

Monetary Policy: (Demand Management Reactions to Inflation)

(3) $m_s = \overset{*}{\kappa}_1 y_p + \overset{*}{\kappa}_2 p + \overset{*}{\kappa}_3 u$ $\kappa_2 < 0$

(4) $m_d = \mu_1 y + \mu_2 \dot{r} + \mu_3 \dot{\pi}$ $\mu_2 < 0$

(5) $m = m_s = m_d$

Total Investment:

(6) $k = \Theta_1 y + \Theta_2 r + \Theta_3 U_k$ $k = (I-I_A)/Y_{-1}, \Theta_2 = (\theta_2'/Y_{-1}) < 0$

(7) $h = \delta_1 y + \delta_2 g_H^*$ $h = (I_H+G_H)/Y_{-1}, g_H = G_H/Y_{-1}$

(8) $a = \varepsilon_1 y + \varepsilon_2 r + \varepsilon_3 g_A^*$ $a = (I_A+G_A)/Y_{-1}, g_A = G_A/Y_{-1}$

Aggregate Demand (Flow Equilibrium) and Fiscal Policy:

(9) $y_d = c + k + h + a + q* + \bar{f} - 1,$ $g = (G-G_H-G_A)/Y_{-1}, f = \bar{F}/Y_{-1}$

(10) $c = \lambda_0 + \lambda_1(y-t+\bar{r})$ $c = (C-I_H)/Y_{-1}$

(11) $y = y_s = y_d$ $t = T/Y_{-1}, \bar{r} = \bar{R}/Y_{-1}$

Table 3 (continued)

Labor Requirements, Under-employment Equilibrium and Underutilization:

(12) $n = (1/\gamma)y - (\gamma_7/\gamma)k$ $\qquad n = (N-N_{-1})/N_{-1}$

(13) $U = (\overline{N}_p - N)/\overline{N}_p$ $\qquad$ by definition of U,

(14) $U_{H,K} = U_H = U_K = U,$ $\qquad$ a simplifying assumption.

Variables are defined in the text under Eqs. (1-5) except for:

G_H = government investment in human capital, and in R&D (G_A), which are netted from Government Purchases of Goods and Services ($G = (1+g^*)G_{-1}$).

I_H = household investment in human capital, which is netted from Personal Consumption Expenditure (C) for inclusion in h.

I_A = business investment in R&D, which is netted from Gross Private Domestic Investment (I) for inclusion in a.

y = percent rate of change in real Gross Domestic Product (Y) demanded (y_D) and supplied (y_S) during the medium term, (5 year) period, with $y = (Y-Y_{-1})/Y_{-1}$.

r = the real rate of interest, so that $r = (1+\dot{r})r_{-1}$.

$\dot{\pi}$ = percent rate of change in the expected inflation rate.

n = percent rate of change in employment of labor demanded (n_D) and supplied (n_S) during the medium term (5 year) period.

T = total tax receipts, $\overline{R}$ = transfer payments, and

U = percent underutilization of human capital (labor hoarding by firms, U_H), physical capital (percent excess capacity) (U_K), raw labor unemployed (U), so that $U = (1+u)U_{-1}$.

Greek letters are all constant-term coefficients.

*Symbolizes policy-determined parameters and variables.

Overbar symbolizes exogenous variables, and for purposes of an instantaneous (medium term) equilibrium, all lagged endogenous variables can be regarded as predetermined.

through its effect in Eq. (9), with feedback effects reducing consumption demand in Eq. (10), and the growth of employment in Eq. (12). The resulting slack demand and unemployment shown in Eqs. (13-14), slow the inflation rate directly via Eq. (2) as well as indirectly as price expectations (π) eventually readjust. But the slower income growth and slack demand also slow total capital formation as shown in Eqs. (6-8) and, together with the attendant underutilization, adversely affect productivity growth through Eq. (1). The result is slowed productivity growth, and as especially in the case of Britain, can be stagflation.

Each of these equations expressed in terms of medium term (5 year) rates of growth has been derived (and can be derived by the reader) from its corresponding function expressed in terms of absolute levels. The derivations will not be shown here because of the space that would be required (except for the derivation of the productivity growth equation shown in the Appendix). The only exception to such a derivation is the reduced-form Phillips equation, Eq. (2), which however has become quite standard. The rates of change (which must be expressed in different form a ratios such as $c = C/Y_{-1}$ to be consistent in Eqs. (6-11) because the aggregate demand components are additive) all are defined here to relate to medium term (5 year) periods. Since the model is linear, it can be solved simultaneously for a medium term (or intermediate-term) equilibrium by treated the lagged endogenous variables as parameters, which then determines a solution for each of the 16 endogenous variables including these rates of change. This includes a solution for the rate of productivity growth in any given 5 year period.

Looked at from an estimation point of view, its behavioral coefficients, expressed in Table 3 in Greek symbols, can be estimated by simultaneous equation methods, regarding the lagged endogenous variables (as well as the exogenous variables) as predetermined for estimation purposes. The simultaneous equation bias that results, for example, from the simultaneous affects of R&D on income growth, and of income growth in turn on support for R&D, would thereby be eliminated. The result should be a more precise measure of each effect on productivity growth in the medium term.

Much more could of course be said about this structural model and its properties. But enough has been said above and in Table 3 to give a clear view of the usefulness of a more explicit simultaneous equation model both for more precise measurement and for a structural interpretation of the sources of the slowdown in productivity growth.

Conclusion

In conclusion, let me summarize the sources of the slowdown in labor productivity growth in the medium term as first, slack demand and investment following the oil price shocks in 1973, and second the loss of the "advantage of backwardness." Third, an important source of labor productivity growth, if not of the slowdown, is human capital formation. Fourth, some types of R&D such as the type of R&D that supports adaptation of western technology in Japan. I would only hope that to restore growth, rather than using beggar-thy-neighbor policies, (such as limiting scientific and social-scientific interchange), the possibilities of a broader concept of total capital and hence of total investment in education and in R&D, irrespective of what sector does it, would not be overlooked. Investment in primary, secondary, and higher education and in R&D have the further advantage of being less energy-intensive forms of investment. Combined with some energy-saving types of investment in physical capital goods, human capital formation and knowledge-capital formation through R&D would appear to offer significant promise for helping to avoid stagflation while simultaneously aiding labor productivity growth.

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Appendix

The sources of productivity growth given by equation (1) in the text may be derived from the following production function:

$$Y = e^{\gamma_1 U_{HK} t} e^{\gamma_2 (Y/N) t} N (A_K K)^{\gamma_3} (A_H H)^{\gamma_4} A^{\gamma_5} E^{\gamma_6} \tag{1a}$$

Terms not already defined above under equation (1) are:

Y = real GDP, e = base of natural logs,

N = employment of new labor,

A = the stock of knowledge, embodied in physical capital through replacement (and net new) investment (A_K), in human capital through education and on-the-job training (A_H), and disembodied new research discoveries (A).

E = petroleum-energy inputs

Taking the logs:

(1b) $$\ln Y = \gamma_1 Ut + \gamma_2 (Y/N)t + \gamma \ln N + \gamma_3 (\ln A_K + \ln K) + \gamma_4 (\ln A_H + \ln H) + \gamma_5 \ln A + \gamma_6 \ln E$$

Differentiating with respect to time, and using simpler lower case notation for percentage rates of change gives:

(1c) $$y = \gamma_1 U + \gamma_2 (Y/N) + \gamma n + \gamma_3 (a_K + k_K) + \gamma_4 (a_H + h_H) + \gamma_5 a + \gamma_6 e$$

Assuming constant returns to scale among the inputs,

(1d) $\gamma = 1 - \gamma_3 - \gamma_4 - \gamma_6$, n can be subtracted from both sides.

Letting gross investment represent net investment plus the embodiment of new technology (much of which occurs through replacement investment) so that $k = (I/K)$ for example, with Y_{-1} used as a proxy to measure K, then gives

(1) $$(y-n) = \gamma_1 U + \gamma_2 (Y/N) + \gamma_3 (k-n) + \gamma_4 (h-n) + \gamma_5 a + \gamma_6 (e-n),$$

the same determinants of the rate of growth in labor productivity shown in equation (1) in the text.